DISCOVERY

58(313), January, 2022

Assessing the Stiffness Sensitivity of Gap Graded Asphalt Concrete

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To Cite:
Sarsam SI. Assessing the Stiffness Sensitivity of Gap Graded Asphalt Concrete. *Discovery*, 2022, 58(313), 50-57

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Peer-Review History
Received: 03 November 2021
Reviewed & Revised: 05/November/2021 to 08/December/2021
Accepted: 10 December 2021
Published: January 2022

Peer-Review Model
External peer-review was done through double-blind method.

ABSTRACT

Flexural stiffness of asphalt concrete is susceptible to the environment condition, binder content, and aggregates ingredients. The ability of the flexible pavement to sustain the serviceability against distresses is dependent on the stiffness of the asphalt concrete mixture. In the present assessment, the stiffness susceptibility of asphalt concrete was investigated in terms of flexural stiffness, deformation, and fatigue life. Asphalt concrete mixture was prepared using three percentages of binder content and two types of mineral filler. The asphalt concrete mixtures were subjected to roller compaction. Beam specimens were extracted from the prepared slab samples. Beam specimens were subjected to fatigue life determination under repeated flexural stresses. The specimens were tested under (20 and 0) ºC environment. It was found that mixture prepared with limestone dust filler exhibits higher flexural stiffness by 38.5 % than the mixture prepared with coal fly ash filler. The fatigue life of specimens prepared with coal flyash is higher than that of specimens prepared with limestone dust by (23.2, and 4.8) % for specimens tested at (0 and 20) ºC respectively. The fracture toughness at failure declines by (30.6, and 20) % when the testing temperature rises from (0 to 20) ºC for specimens prepared with coal flyash and limestone dust respectively. Mixture with coal fly ash exhibits higher initial stiffness when the binder content increases by 0.5 % as compared with the control mixture. However, lowering the binder content by 0.5 % is exhibits lower flexural stiffness than that of the control mixture. It was concluded that asphalt concrete mixture prepared with limestone dust is more sensitive to the variation in testing temperature and binder content than the mixture prepared with coal fly ash.

Keywords: Asphalt concrete, Gap, Sensitivity, Flexural stiffness, Deformation, Fatigue life

1. INTRODUCTION

Sensitivity of asphalt concrete stiffness is a main reason for rehabilitation and maintenance requirements. Canestrari, and Ingrassia, 2020 revealed that pavements characterized by open-graded friction courses, which are very common worldwide, present critical issues in terms of cracking due to the high air void content that promotes the development of the distress. A study of the cracking model by Ling et al., 2019 was showed that a greater thickness of the asphalt pavement layers as well as a greater thickness of the base layer does not

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ISSN 2278–5469 EISSN 2278–5450 I OPEN ACCESS

significantly affect the crack initiation time, but they can considerably reduce the longitudinal crack growth rate. The fatigue life of asphalt concrete pavement was monitored by Sarsam, 2021 in terms the number of flexural stresses repetitions to reach the reduction of 50 % in stiffness. It was revealed that the fatigue life increases when implementing additives, while the specimen's practices a constant strain level of 750, 400, and 250 microstrain. It was recommended to use the modified binder with flyash and silica fumes in asphalt concrete to enhance the stiffness and fatigue life and stiffness. Roque et al., 2010 stated that as the stiffness of the base layer increases, the crack initiation is progressively delayed and the crack growth rate in depth is reduced. The mechanical properties of original and fiber reinforced asphalt concrete, were determined by Angel and John, 2019 in the laboratory. It was revealed that adding the fibers can improve the pavement resistance to fatigue at high microstrain levels and the rutting resistance considerably. It was concluded that adding fibers would be of influence where asphalt concrete is subjected to high strain levels. Marasteanu et al., 2019 revealed the properties of asphalt concrete are highly temperature dependent, and the ranking observed at one temperature can change at a different temperature. In addition, it was observed that materials having similar rheological properties, such as creep stiffness, do not exhibit the same resistance to fracture. It was concluded that these results confirm one more time the need for a fracture/strength test for correctly evaluating cracking resistance of asphalt materials. Karami, 2020 evaluated the fatigue strength of asphalt concrete using the four-point bending beam under repeated flexural bending test. The beam was tested under the controlled-strain mode of loading at 20°C test temperature. Three different peak tensile strain including 800, 600, and 400 microstrain, 10 Hz loading frequency, continuous haversine mode of loading were implemented. Test results revealed that the strain-stiffness approach exhibited that the initial flexural stiffness influenced the fatigue life for the mixtures. Schanz and Abdulsattar, 2013 stated that the fracture toughness increases by 57.5 % as the test temperature decreases, this may indicate that the asphalt concrete gets brittle at cold temperatures. It was concluded that as the temperature decrease, the fracture energy deceases but the fracture toughness increases. Fatigue tests were performed by Tapkin, 2014 using repeated indirect tensile test apparatus under controlled stress conditions. For determination of the fatigue life of asphalt concrete, the start of macro crack was considered as an acceptable criterion for termination of the test. It was revealed that the effect of replacing fly ash and composition on the physical properties of mixtures such as fatigue life can be estimated without carrying out destructive tests. Vega et al., 2021 reported that the testing temperature and the specimen thickness did not exhibit statistical influence on the stress intensity factor. However, the specimen thickness exhibits impact on fracture energy. Coleri et al., 2018 characterized the impact of asphalt concrete mixture properties, aggregate gradation, asphalt binder content, ageing, and air-void content, on cracking behavior of asphalt mixtures. Recommended strategies were proposed to address the early failure of pavement by fatigue based on the testing results, and statistical analysis. Pirmohammad and Ayatollahi, 2014 assessed the influence of testing temperature and loading mode on the resistance to fracture of asphalt concretes under dynamic loading. It was revealed that both loading modes and temperature influence the resistance to fracture of asphalt concrete significantly. It was concluded that the resistance to fracture of asphalt concretes pavement exhibits increase at the beginning, and then below a temperature of (−20 °C) decreased.

The aim of this investigation is to assess the stiffness sensitivity of gap graded asphalt concrete in terms of flexural stiffness, deformation, and fatigue life. The influence of two types of mineral filler, three percentages of binder content, and two testing temperature on the cracking phenomena will be assessed. The repeated four-points flexural bending beam test will be implemented for this investigation.

2. MATERIALS AND METHODS

Asphalt Cement

Asphalt cement binder of 40-50 penetration grad was implemented in this work. It was obtained from AL-Nasiriya oil Refinery. The physical properties of the asphalt binder are listed in Table 1.

Table 1. Physical Properties of Asphalt Cement Binder

Physical properties	ASTM, 2016 Designation	Asphalt cement
Penetration	D5-06	42
Softening Point °C	D36-95	49
Ductility Cm	D113-99	150+
Specific Gravity	D70	1.04
Flash Point °C	D92-05	269
After thin film oven test		
Retained Penetration of Residue	D5-06	33

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Loss in weight (163°C, 50g,5h) %	D-1754	0.175
Ductility of Residue	D113-99	130 cm

Coarse and Fine Aggregates

Crushed coarse aggregates having a nominal maximum size of 19 mm and retained on sieve No. 4 was obtained from AL-Ukhaider quarry. Crushed and natural sand mixture was implemented as Fine aggregate (which passes sieve No.4 and retained on sieve No.200). It was obtained from the same source. The aggregates were washed, air dried and separated into different sizes by sieving. The physical properties of aggregates are listed in Table 2.

Table 2. The Physical Properties of Coarse and Fine Aggregate as per ASTM, 2016

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity (ASTM C 127 and C 128).	2.642	2.658
Percent Water Absorption (ASTM C 127 and C 128)	1.07	1.83
Percent Wear (Los-Angeles Abrasion) (ASTM C 131)	18 %	-

Mineral Filler

Two types of mineral filler are implemented in the present investigation, the first one is the limestone dust which was obtained from Karbala plant. The physical properties of the limestone dust mineral filler are listed in Table 3. The second type is coal fly ash which was obtained from local market. The physical properties of the fly ash mineral filler are listed in Table 4.

Table 3. The Physical Properties of Limestone Dust Mineral Filler

Property	Test Value
Bulk specific gravity	2.617
Passing Sieve No.200 %	94

Table 4. The Physical Properties of Coal Flyash Mineral Filler

Maximum Sieve size mm	% Passing	Specific gravity	Specific surface area (m^2/ kg)
0.075	98	2.645	650

Selection of Aggregates Combined Gradation

One type of aggregates gradation was selected in the present investigation. It follows Road Note 31, of the British standard specification for Gap graded wearing course pavement layer with 12.5 mm nominal maximum size of aggregates. Figure 1 shows the selected aggregate gradation and the limitations of the specification.

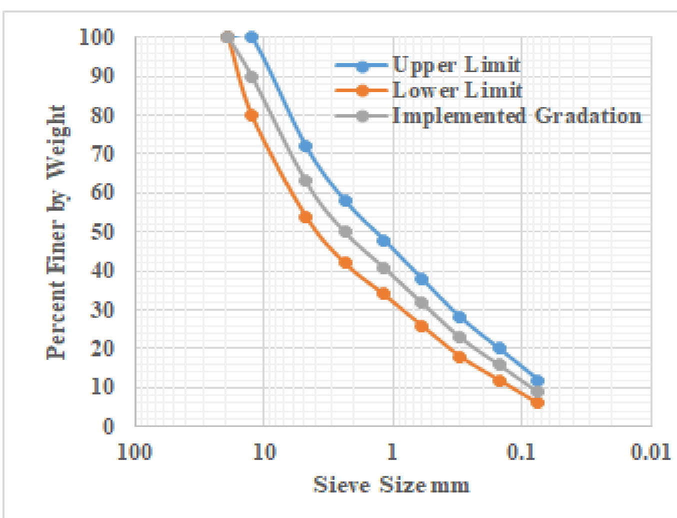

Figure 1. Combined Gradation Adopted

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Preparation of Asphalt Concrete Mixture and Specimens

The mineral filler was combined with fine and coarse aggregates to meet a specific gradation for wearing course. The combined aggregates were then heated to 160 ºC before it was mixed with asphalt cement. The asphalt cement binder was heated to 150 ºC then, the binder was introduced into the heated combined aggregates to the required amount, then mixed thoroughly using a spatula for two minutes so that the aggregate particles are coated with a thin film of the binder; the optimum binder content of (4.5, and 4.7) % for mixtures with coal flyash and limestone dust filler types respectively. The optimum binder percentage was determined based on Marshall trial mixes using various asphalt percentages. Details of obtaining the optimum binder content could be found in Sarsam and Sultan, 2015. Table 5 presents the Marshall properties of the prepared asphalt concrete mixtures.

Table 5. Marshall Properties of the Prepared Mixtures

Filler type	Optimum binder %	Marshall Stability kN	Marshall Flow mm	Bulk density gm/cm^3	Vv %	VMA %	VFB %
Limestone Dust	4.7	9.5	3.3	2.295	4	14.3	72
Coal Flyash	4.5	12.6	3.1	2.301	4.1	14.4	70.4

The mixtures were casted in a slab mold of (400 x 300 x 63) mm and subjected to roller compaction to the target bulk density for each binder content according to EN12697-33, 2007. The applied static load was 5 kN while the number of load passes depended on the asphalt content and target bulk density of the mixture and was determined based on trial-and-error process. Details of the compaction process could be found in Sarsam, 2016. The compaction temperature was maintained to 150 °C. Slab samples were left to cool overnight. The number of casted slabs was four. Beam specimens of 50 mm width, 63 mm depth, and 400 mm length were obtained from the compacted slab sample using the Diamond saw. The total number of beam specimens was twelve. Beam specimens were subjected to repeated flexural bending for fatigue life determination using four point bending beam test under controlled Microstrain of 400 as per AASHTO, T321, 2010. The test was terminated when the flexural stiffness declines by 50 % of its original value. Figure 2 exhibit the roller compactor implemented and the flexural fatigue beam test. All the testing program was conducted at (0, and 20) °C environment.

Figure 2. Roller Compactor and Flexural bending beam Test

3. RESULTS AND DISCUSSIONS

Influence of filler type on the Fatigue life and Fracture Toughness

Mineral filler of two types have been implemented in preparing the asphalt concrete mixtures, coal Fly ash and Limestone dust. Figure 3 demonstrates the influence of filler type on fatigue life and the fracture toughness of asphalt concrete. It can be observed that higher fracture toughness could be achieved when the limestone dust was used as mineral filler regardless of the testing temperature. However, the fatigue life of the specimens prepared with coal flyash is higher than that of specimens prepared with limestone dust by (23.2, and 4.8) % for specimens tested at (0 and 20) ºC respectively. However, the fracture toughness at failure declines by (30.6, and 20) % when the temperature of testing rises from (0 to 20) ºC for specimens prepared with coal flyash and limestone dust respectively. It can be revealed that the fracture toughness of asphalt concrete is susceptible to the testing temperature and type of mineral filler. Similar finding was reported by Sarsam, 2021.

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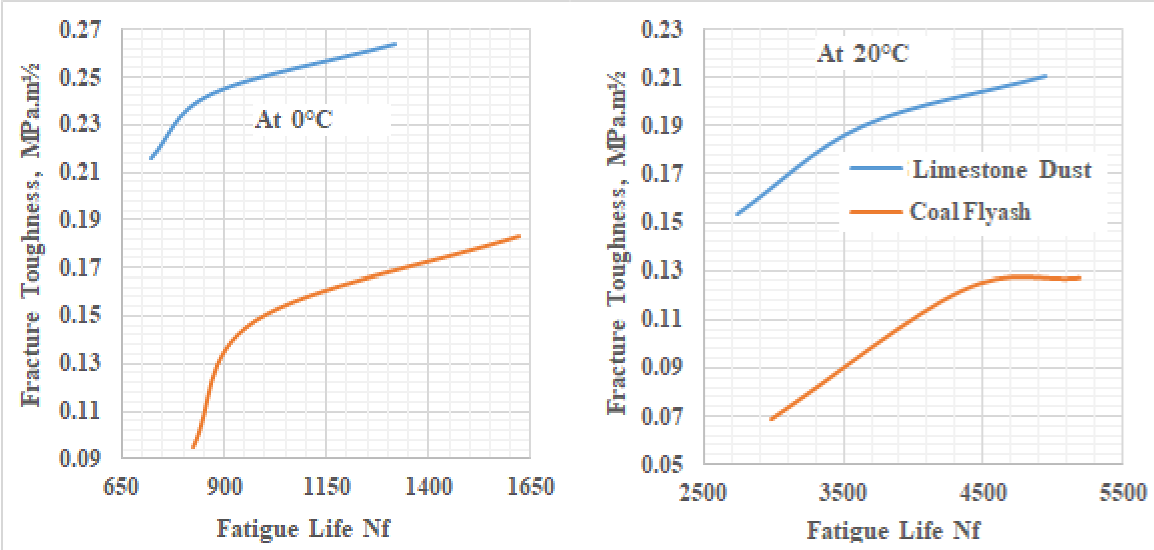

Figure 3. Influence of filler type on Fracture Toughness and Fatigue Life

Influence of Filler Type on Flexural Stiffness of Asphalt Concrete

Figure 4 demonstrates the influence of filler type on the flexural stiffness and fatigue life of asphalt concrete mixtures prepared at optimum binder content and tested at 20º C environment. It can be noticed that the flexural stiffness declines sharply at early stages of loading up to 10 load cycles regardless of the filler type, then declines gently. Mixture prepared with limestone dust filler exhibits higher flexural stiffness by 38.5 % than the mixture prepared with coal fly ash filler. However, the variation in the flexural stiffness was not significant when the test was terminated after 50 % reduction of stiffness. This may be related to more fines content in the mixture which contains fly ash as compared with mixture with limestone dust. On the other hand, asphalt concrete mixture with fly ash exhibits higher fatigue life by 16.2 % as compared with the mixture with limestone dust. Such behavior agrees with Marasteanu et al., 2019.

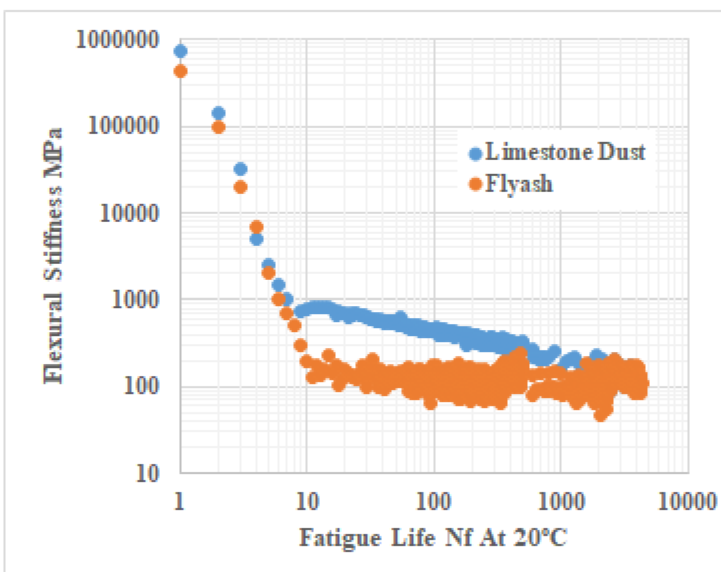

Figure 4. Influence of Filler Type on Flexural Stiffness and Fatigue Life

Influence of Testing Temperature on Flexural Stiffness

Figure 5 exhibits the influence of testing temperature on the flexural stiffness and fatigue life of the asphalt concrete. Lower fatigue life of 75 % could be noticed at 0º C regardless of the filler type as compared with the 20º C testing environment. It can be observed that mixture with limestone dust exhibit higher flexural stiffness at 20º C testing temperature than the mixture tested at 0º C, while the mixture with coal fly ash exhibits lower flexural stiffness at 0º C than that tested at 20º C. However, there is no significant variation in the flexural stiffness or the fatigue life between the two mixtures when tested at 0º C environment.

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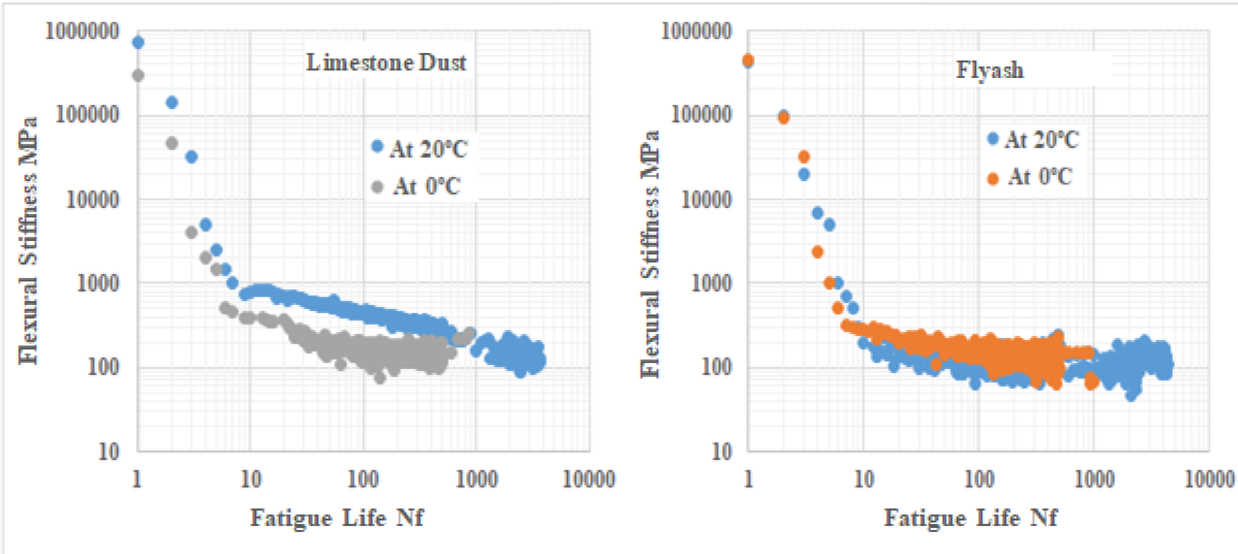

Figure 5. Influence of Testing Temperature on the Flexural Stiffness of Asphalt Concrete

This could be attributed to the brittle nature of both mixtures at 0º C environment. Asphalt concrete mixture with limestone dust filler exhibits higher flexural stiffness by (350, and 66.6) % than that of mixture with coal flyash filler after 10 load repetitions when tested at (20 and 0) ºC environment. It can be revealed that asphalt concrete mixture prepared with limestone dust is more susceptible to the variation in testing temperature than the mixture prepared with coal fly ash. Such finding agrees with Tapkin, 2014.

Influence of Binder Content on Flexural Stiffness

Figure 6 exhibits the influence of asphalt binder content on the flexural stiffness of asphalt concrete. It can be observed that mixture with limestone dust shows lower initial stiffness when the binder content was decreased or increased by 0.5 % than the optimum binder content. However, higher binder content of 0.5 % exhibits higher flexural stiffness after the third repetition of load, while lower binder content of 0.5 % shows declines in the flexural stiffness. On the other hand, asphalt concrete mixture with coal fly ash exhibits higher initial stiffness when the binder content increases by 0.5 % as compared with the control mixture. However, lowering the binder content by 0.5 % is exhibits lower flexural stiffness as compared to that of the control mixture. It can be revealed that in general, mixtures with limestone dust are stiffer and more susceptible to the variation in binder content than those with coal flyash regardless of the binder content. Similar behavior was reported by Coleri et al., 2018.

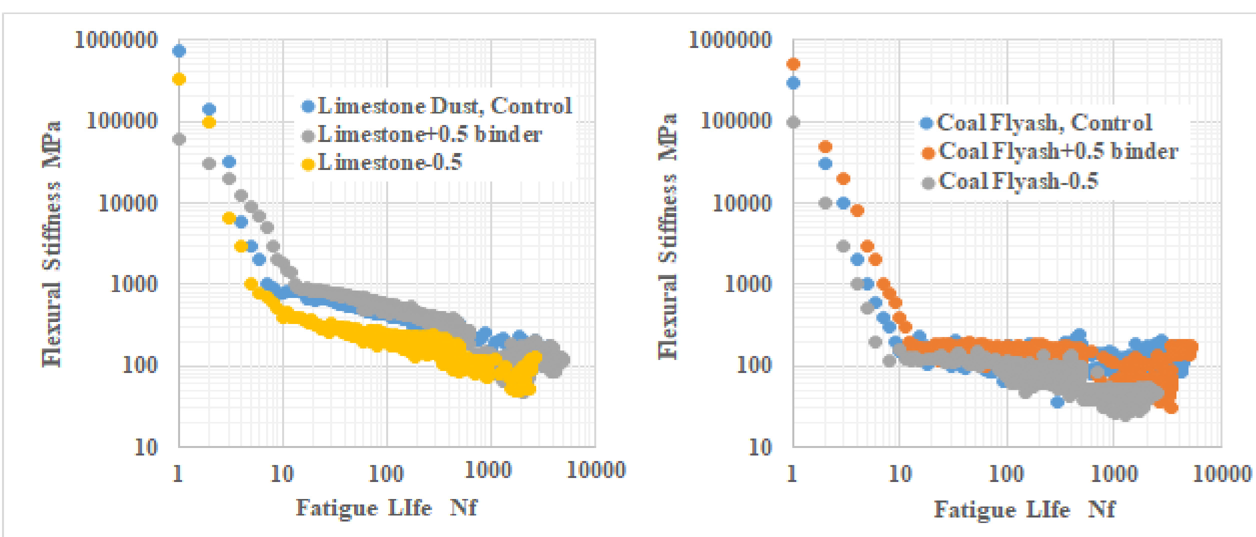

Figure 6. Influence of Binder Content on Flexural Stiffness and Fatigue Life

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Influence of Filler Type and Testing Temperature on Permanent Deformation-stiffness relationship

Figure 7 demonstrates the influence of filler type and testing temperature on permanent microstrain of asphalt concrete. It can be noticed that as the stiffness of asphalt concrete declines, the permanent deformation increases regardless of the testing temperature. It can be noted that the testing temperature has more influence on asphalt concrete mixture prepared with coal flyash than that prepared with limestone dust.

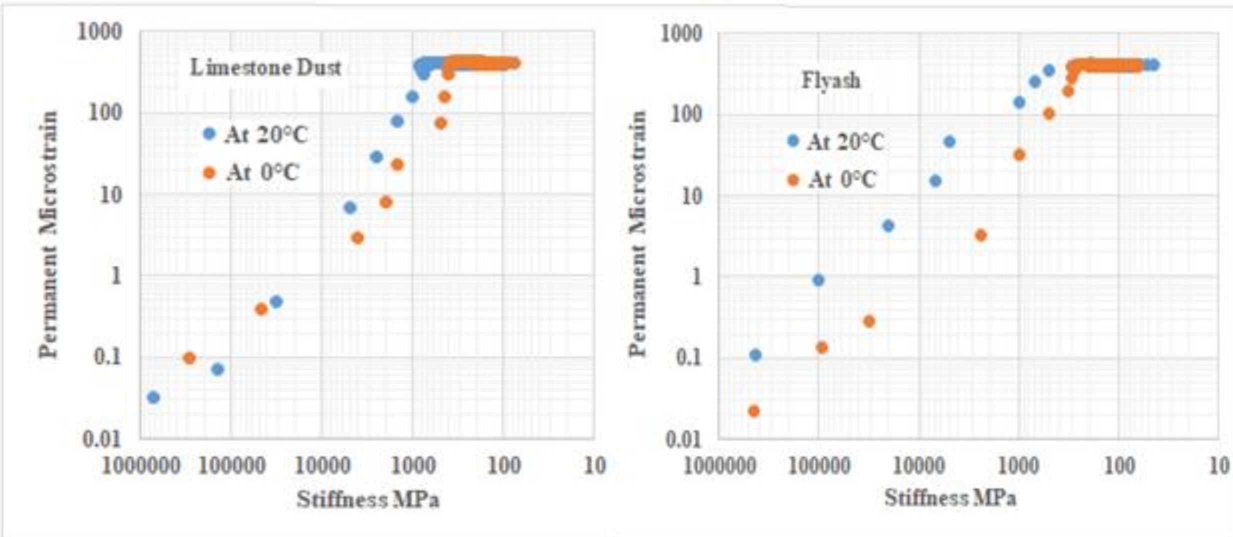

Figure 7. Deformation-Stiffness relationship

4. CONCLUSIONS

According to the implemented testing and the properties of materials, the following concluding remarks can be addressed.

1- The fatigue life of asphalt concrete specimen prepared with coal flyash is higher than that of specimens prepared with limestone dust by (23.2, and 4.8) % for specimens tested at (0 and 20) ºC respectively.

2- The fracture toughness at failure declines by (30.6, and 20) % for the testing temperature which rises from (0 to 20) ºC for specimens prepared with coal flyash and limestone dust respectively.

3- Mixture prepared with limestone dust filler exhibits higher flexural stiffness by 38.5 % than the mixture prepared with coal fly ash filler. However, asphalt concrete mixture with fly ash exhibits higher fatigue life by 16.2 % as compared with the mixture with limestone dust.

4- Asphalt concrete mixture with limestone dust filler exhibits higher flexural stiffness by (350, and 66.6) % than that of mixture with coal flyash filler after 10 load repetitions when tested at (20 and 0) ºC environment.

5- Mixtures with limestone dust are stiffer and more susceptible to the variation in binder content than those with coal flyash regardless of the binder content.

6- The fracture toughness of the asphalt concrete mixture is susceptible to the testing temperature and type of mineral filler. However, asphalt concrete mixture prepared with limestone dust is more susceptible to the variation in testing temperature than the mixture prepared with coal fly ash.

Funding

This study has not received any external funding.

Conflicts of interests

The authors declare that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

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